

**SERVO WRITING A DISK DRIVE BY SYNCHRONIZING A SERVO WRITE CLOCK
IN RESPONSE TO A SYNC MARK RELIABILITY METRIC**

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to disk drives for computer systems. More particularly, the present invention relates to servo writing a disk drive by synchronizing a servo write clock in response to a sync mark reliability metric.

Description of the Prior Art

When manufacturing a disk drive, product servo sectors 2₀-2₇ are written to a disk which define a plurality of radially-spaced, concentric data tracks 6 as shown in the prior art disk format of FIG. 1. Each product servo sector (e.g., servo sector 2₄) comprises a preamble 8 for synchronizing gain control and timing recovery, a sync mark 10 for synchronizing to a data field 12 comprising coarse head positioning information such as a track number, and servo bursts 14 which provide fine head positioning information. During normal operation the servo bursts 14 are processed by the disk drive in order to maintain a head over a centerline of a target track while writing or reading data. In the past, external servo writers have been used to write the product servo sectors 2₀-2₇ to the disk surface during manufacturing. External servo writers employ extremely accurate head positioning mechanics, such as a laser interferometer, to ensure the product servo sectors 2₀-2₇ are written at the proper radial location from the outer diameter of the disk to the inner diameter of the disk. However, external servo writers are expensive and require a clean room environment so that a head positioning pin can be inserted into the head disk assembly (HDA) without contaminating the disk. Thus, external servo writers have become an expensive bottleneck in the disk drive manufacturing process.

The prior art has suggested various "self-servo" writing methods wherein the internal electronics of the disk drive are used to write the product servo sectors independent of an external servo writer. For example, U.S. Patent No. 5,668,679 teaches a disk drive which

1 performs a self-servo writing operation by writing a plurality of spiral tracks to the disk which
2 are then processed to write the product servo sectors along a circular path. Each spiral track is
3 written to the disk as a high frequency signal (with missing bits), wherein the position error
4 signal (PES) for tracking is generated relative to time shifts in the detected location of the spiral
5 tracks. In addition, the '679 patent generates a servo write clock by synchronizing a phase-
6 locked loop (PLL) to the missing bits in the spiral tracks. However if the signal-to-noise ratio
7 (SNR) of the read signal is low (e.g., over a media defect), a missing bit may not be detected or
8 falsely detected at the wrong time creating transients in the PLL which degrades the servo writing
9 process.

10 There is, therefore, a need to better synchronize a servo write clock when servo writing a
11 disk drive by servoing on spiral tracks.

12 SUMMARY OF THE INVENTION

13 The present invention may be regarded as a method of writing product servo sectors to a
14 disk of a disk drive. The disk drive comprises control circuitry and a head disk assembly (HDA)
15 comprising the disk, an actuator arm, a head connected to a distal end of the actuator arm, and a
16 voice coil motor for rotating the actuator arm about a pivot to position the head radially over the
17 disk. The disk comprises a plurality of spiral tracks, wherein each spiral track comprises a high
18 frequency signal interrupted at a predetermined interval by a sync mark. The head internal to the
19 disk drive is used to read the spiral tracks to generate a read signal. The read signal is processed
20 to detect a sync mark in a spiral track and to generate an associated sync mark reliability metric,
21 wherein the sync mark reliability metric representing a probability that the sync mark was
22 detected accurately. A timing recovery measurement is generated in response to the detected
23 sync mark and the sync mark reliability metric, and a servo write clock is synchronized in
24 response to the timing recovery measurement. The read signal representing the high frequency
25 signal in the spiral track is processed to generate a position error signal used to maintain the head
26 along a substantially circular target path, and the servo write clock and the head internal to the
27 disk drive are used to write the product servo sectors along the circular target path.

1 In one embodiment, the sync mark reliability metric is generated by processing the read
2 signal to generate an estimated data sequence and correlating the estimated data sequence with a
3 sync mark pattern.

4 In still another embodiment, the sync mark reliability metric is generated by rectifying the
5 read signal and generating a DC component of the rectified read signal.

6 In yet another embodiment, the sync mark reliability metric is generated by sampling the
7 read signal to generate a sequence of read signal sample values, processing the read signal
8 sample values to generate expected sample values, and generating a mean squared error (MSE)
9 from the difference between the expected sample values and the read signal sample values.

10 In another embodiment, the sync mark reliability metric is generated by rectifying the
11 read signal, integrating the rectified read signal, and generating the sync mark reliability metric
12 and the position error signal from the integration.

13 In yet another embodiment, if the sync mark reliability metric is above a threshold, the
14 timing recovery measurement is generated in response to the detected sync mark. Otherwise, the
15 detected sync mark is ignored. If a consecutive number of ignored sync marks exceeds a
16 predetermined number and the next sync mark reliability metric is below the threshold, the
17 timing recovery measurement is generated in response to the detected sync mark.

18 In one embodiment, the control circuitry within the disk drive is used to read the spiral
19 tracks in order to synchronize the servo write clock. In an alternative embodiment, an external
20 product servo writer is used to read the spiral tracks in order to synchronize the servo write clock.

21 The present invention may also be regarded as a disk drive comprising a disk having a
22 plurality of spiral tracks, wherein each spiral track comprises a high frequency signal interrupted
23 at a predetermined interval by a sync mark. The disk drive further comprises an actuator arm, a
24 head connected to a distal end of the actuator arm, and a voice coil motor for rotating the actuator
25 arm about a pivot to position the head radially over the disk. The head internal to the disk drive is
26 used to read the spiral tracks to generate a read signal. The read signal is processed to detect a
27 sync mark in a spiral track and to generate an associated sync mark reliability metric, wherein the

1 sync mark reliability metric representing a probability that the sync mark was detected accurately.
2 A timing recovery measurement is generated in response to the detected sync mark and the sync
3 mark reliability metric, and a servo write clock is synchronized in response to the timing
4 recovery measurement. The read signal representing the high frequency signal in the spiral track
5 is processed to generate a position error signal used to maintain the head along a substantially
6 circular target path, and the servo write clock and the head internal to the disk drive are used to
7 write product servo sectors along the circular target path.

8 BRIEF DESCRIPTION OF THE DRAWINGS

9 FIG. 1 shows a prior art disk format comprising a plurality of radially spaced, concentric
10 tracks defined by a plurality of product servo sectors.

11 FIG. 2A and 2B illustrate an embodiment of the present invention wherein an external
12 spiral servo writer is used to write a plurality of spiral tracks to the disk for use in writing product
13 servo sectors to the disk.

14 FIG. 3A shows an embodiment of the present invention wherein a servo write clock is
15 synchronized by clocking a modulo-N counter relative to when the sync marks in the spiral tracks
16 are detected.

17 FIG. 3B shows an eye pattern generated by reading the spiral track, including the sync
18 marks in the spiral track.

19 FIG. 4 illustrates an embodiment of the present invention wherein synchronization of the
20 servo write clock is maintained from a coarse timing recovery measurement generated in
21 response to the sync marks recorded in the spiral tracks and a fine timing recovery measurement
22 generated in response to the high frequency signal in the spiral tracks.

23 FIG. 5 shows circuitry according to an embodiment of the present invention for
24 generating the servo write clock including a sync detector for detecting the sync marks in the
25 spiral tracks together with a sync mark reliability metric used by a timing recovery circuit to
26 generate a timing recovery measurement.

FIG. 6 shows an embodiment of the sync mark detector including a data detector and a correlator for correlating a detected data sequence with the sync mark pattern, wherein the correlation is compared to a threshold to detect the sync mark and the correlation is also the sync mark reliability metric.

FIG. 7A shows an embodiment of the present invention wherein the sync mark reliability metric is generated by computing the average magnitude of the rectified read signal.

FIG. 7B shows an embodiment of the present invention wherein the sync mark reliability metric is generated by computing a mean squared error (MSE) between expected and actual read signal sample values.

FIG. 8 shows an embodiment of the present invention wherein the sync mark reliability metric is generated by a position error signal (PES) generator which processes (e.g., rectifies and integrates) the high frequency signal in the spiral tracks to generate a PES signal used for tracking.

FIG. 9 shows a flow diagram according to an embodiment of the present invention wherein a timing recovery measurement is not generated if the sync mark reliability metric is too low unless a predetermined number of consecutive sync marks have been ignored.

FIG. 10 shows an embodiment of the present invention wherein an external product servo writer is used to process the spiral tracks in order to write the product servo sectors to the disk.

FIG. 11 shows an embodiment of the present invention wherein an external spiral servo writer is used to write the spiral tracks, and a plurality of external product servo writers write the product servo sectors for the HDAs output by the external spiral servo writer.

FIG. 12 shows an embodiment of the present invention wherein an external spiral servo writer is used to write the spiral tracks, and the control circuitry within each product disk drive is used to write the product servo sectors.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

FIGs. 2A and 2B show a disk drive 16 according to an embodiment of the present invention comprising a disk 18 having a plurality of spiral tracks 20_0 - 20_N , wherein each spiral

1 track 20 comprises a high frequency signal 22 interrupted at a predetermined interval by a sync
2 mark 24 (FIG. 3B). The disk drive 16 further comprises an actuator arm 26, a head 28 connected
3 to a distal end of the actuator arm 26, and a voice coil motor 30 for rotating the actuator arm 26
4 about a pivot to position the head 28 radially over the disk 18. The head 28 internal to the disk
5 drive 16 is used to read the spiral tracks 20_0 - 20_N to generate a read signal. The read signal is
6 processed to detect a sync mark 24 in a spiral track 20 and to generate an associated sync mark
7 reliability metric, wherein the sync mark reliability metric representing a probability that the sync
8 mark 24 was detected accurately. A timing recovery measurement is generated in response to the
9 detected sync mark 24 and the sync mark reliability metric, and a servo write clock is
10 synchronized in response to the timing recovery measurement. The read signal representing the
11 high frequency signal 22 in the spiral track 20 is processed to generate a position error signal
12 used to maintain the head 28 along a substantially circular target path, and the servo write clock
13 and the head 28 internal to the disk drive are used to write the product servo sectors along the
14 circular target path.

15 In the embodiment of FIG. 2A, the disk 18, actuator arm 26, head 28 and voice coil motor
16 30 are enclosed in a head disk assembly (HDA) 32 of the disk drive 16. The disk drive 16 further
17 comprises control circuitry 34 mounted on a printed circuit board for controlling operation of the
18 disk drive 16. In one embodiment, the control circuitry 34 writes the spiral tracks 20_0 - 20_N to the
19 disk 18 and then processes the spiral tracks 20_0 - 20_N to write the product servo sectors to the disk
20 18.

21 In an alternative embodiment shown in FIG. 2A, an external spiral servo writer 36 is used
22 to write the spiral tracks 20_0 - 20_N to the disk 16. The external spiral servo writer 36 comprises a
23 head positioner 38 for actuating a head positioning pin 40 using sensitive positioning circuitry,
24 such as a laser interferometer. Pattern circuitry 42 generates the data sequence written to the disk
25 18 for the spiral tracks 20_0 - 20_N . The external spiral servo writer 36 writes a clock track 44 (FIG.
26 2B) at an outer diameter of the disk 18, and a clock head 46 is inserted into the HDA 32 for
27 reading the clock track 44 to generate a clock signal 48. Timing circuitry 50 in the external spiral

1 servo writer 36 processes the clock signal 48 to enable the pattern circuitry 42 at the appropriate
2 time so that the spiral tracks 20_0 - 20_N are written at the appropriate circumferential location. The
3 clock signal 48 also enables the pattern circuitry 42 to write the sync marks 24 (FIG. 3B) within
4 the spiral tracks 20_0 - 20_N at the same circumferential location from the outer diameter to the inner
5 diameter of the disk 18. As described below with reference to FIG. 4, the constant interval
6 between sync marks 24 (independent of the radial location of the head 28) enables the servo write
7 clock to maintain synchronization.

8 In the embodiment of FIG. 2A, the entire disk drive 16 is shown as being inserted into the
9 external spiral servo writer 36. In an alternative embodiment, only the HDA 32 is inserted into
10 the external spiral servo writer 36.

11 After the external spiral servo writer 36 writes the spiral tracks 20_0 - 20_N to the disk 18, the
12 head positioning pin 40 and clock head 46 are removed from the HDA 32 and the product servo
13 sectors are written to the disk 18. In one embodiment, the control circuitry 34 within the disk
14 drive 16 is used to process the spiral tracks 20_0 - 20_N in order to write the product servo sectors to
15 the disk 18. In an alternative embodiment described below with reference to FIGs. 10 and 11, an
16 external product servo writer is used to process the spiral tracks 20_0 - 20_N in order to write the
17 product servo sectors to the disk 18 during a "fill operation".

18 FIG. 3B illustrates an "eye" pattern in the read signal that is generated when the head 28
19 passes over a spiral track 20. The read signal representing the spiral track comprises high
20 frequency transitions 22 interrupted by sync marks 24. When the head 28 moves in the radial
21 direction, the eye pattern will shift (left or right) while the sync marks 24 remain fixed. The shift
22 in the eye pattern (detected from the high frequency signal 22) relative to the sync marks 24
23 provides the off-track information for servoing the head 28.

24 FIG. 3A shows an embodiment of the present invention wherein a saw-tooth waveform
25 52 is generated by clocking a modulo-N counter with the servo write clock, wherein the
26 frequency of the servo write clock is adjusted until the sync marks 24 in the spiral tracks 20_0 - 20_N
27 are detected at a target modulo-N count value. The servo write clock may be generated using any

1 suitable circuitry. In one embodiment, the servo write clock is generated using a phase locked
2 loop (PLL). As each sync mark 24 in the spiral tracks 20_0 - 20_N is detected, the value of the
3 modulo-N counter represents the phase error for adjusting the PLL. In one embodiment, the PLL
4 is updated when any one of the sync marks 24 within the eye pattern is detected. In this manner
5 the multiple sync marks 24 in each eye pattern (each spiral track crossing) provides redundancy
6 so that the PLL is still updated if one or more of the sync marks 24 are missed due to noise in the
7 read signal. Once the sync marks 24 are detected at the target modulo-N count values, the servo
8 write clock is coarsely locked to the desired frequency for writing the product servo sectors to the
9 disk 18.

10 The sync marks 24 in the spiral tracks 20_0 - 20_N may comprise any suitable pattern, and in
11 one embodiment, a pattern that is substantially shorter than the sync mark 10 in the conventional
12 product servo sectors 2 of FIG. 1. A shorter sync mark 24 allows the spiral tracks 20_0 - 20_N to be
13 written to the disk 18 using a steeper slope (by moving the head 28 faster from the outer diameter
14 to the inner diameter of the disk 18) which reduces the time required to write each spiral track
15 20_0 - 20_N .

16 In one embodiment, the servo write clock is further synchronized by generating a timing
17 recovery measurement from the high frequency signal 22 between the sync marks 24 in the spiral
18 tracks 20_0 - 20_N . Synchronizing the servo write clock to the high frequency signal 22 helps
19 maintain proper radial alignment (phase coherency) of the Gray coded track addresses in the
20 product servo sectors. The timing recovery measurement may be generated in any suitable
21 manner. In one embodiment, the servo write clock is used to sample the high frequency signal
22 22 and the signal sample values are processed to generate the timing recovery measurement. The
23 timing recovery measurement adjusts the phase of the servo write clock (PLL) so that the high
24 frequency signal 22 is sampled synchronously. In this manner, the sync marks 24 provide a
25 coarse timing recovery measurement and the high frequency signal 22 provides a fine timing
26 recovery measurement for maintaining synchronization of the servo write clock.

FIG. 4 illustrates how the product servo sectors 56_0-56_N are written to the disk 18 after synchronizing the servo write clock in response to the high frequency signal 22 and the sync marks 24 in the spiral tracks 20_0-20_N . In the embodiment of FIG. 4, the dashed lines represent the centerlines of the data tracks. The sync marks in the spiral tracks 20_0-20_N are written so that there is a shift of two sync marks in the eye pattern (FIG. 3B) between data tracks. In an alternative embodiment, the sync marks in the spiral tracks 20_0-20_N are written so that there is a shift of N sync marks in the eye pattern between data tracks. In practice the width of the spiral tracks 20_0-20_N in the embodiment of FIG. 4 will be proximate the width of a data track. The spiral tracks 20_0-20_N are shown in FIG. 4 as being wider than the width of a data track for illustration purposes.

The PES for maintaining the head 28 along a servo track (tracking) may be generated from the spiral tracks 20_0-20_N in any suitable manner. In one embodiment, the PES is generated by detecting the eye pattern in FIG. 3B using an envelope detector and detecting a shift in the envelope relative to the sync marks 24. In one embodiment, the envelope is detected by integrating the high frequency signal 22 and detecting a shift in the resulting ramp signal. In an alternative embodiment, the high frequency signal 22 between the sync marks 24 in the spiral tracks are demodulated as servo bursts and the PES generated by comparing the servo bursts in a similar manner as the servo bursts 14 in the conventional servo sectors (FIG. 1).

Once the head 28 is tracking on a servo track, the product servo sectors 56_0-56_N are written to the disk using the servo write clock. Write circuitry is enabled when the modulo-N counter reaches a predetermined value, wherein the servo write clock clocks the write circuitry to write the product servo sector 56 to the disk. The spiral tracks 20_0-20_N on the disk are processed in an interleaved manner to account for the product servo sectors 56_0-56_N overwriting a spiral track. For example, when writing the product servo sectors 56_1 to the disk, spiral track 20_2 is processed initially to generate the PES tracking error and the timing recovery measurement. When the product servo sectors 56_1 begin to overwrite spiral track 20_2 , spiral track 20_3 is processed to generate the PES tracking error and the timing recovery measurement.

FIG. 5 shows details of control circuitry for synchronizing the servo write clock 58. The read signal 60 emanating from the head 28 is sampled 62, and the read signal sample values 64 are processed by a sync mark detector 66 for detecting the sync marks 24 in the spiral tracks 20_0 - 20_N . The sync mark detector 66 generates a sync mark detect signal 68 applied to a timing recovery circuit 70. The timing recovery circuit 70 processes the sync mark detect signal 68 to generate a coarse timing recovery measurement, and the read signal sample values 64 representing the high frequency signal 22 in the spiral tracks 20_0 - 20_N to generate a fine timing recovery measurement. The coarse and fine timing recovery measurements are combined to generate a control signal applied to a write voltage controlled oscillator (VCO) 72 which outputs the servo write clock 58. The servo write clock 58 clocks operation of write circuitry 74 for writing the product servo sectors 56_0 - 56_N to the disk 18. The servo write clock 58 is also fed back into the timing recovery circuit 70 and used to clock the modulo-N counter to generate the coarse timing recovery measurement. The timing recovery circuit 70 generates a sync mark detection window over line 78 for enabling the sync mark detector 66 during a window where a sync mark 24 is expected to occur. The timing recovery circuit 70 also generates a control signal over line 80 to enable the write circuitry 74 to begin writing a product servo sector at the appropriate time.

The sync mark detector 66 generates a sync mark reliability metric 82 applied to the timing recovery circuit 70, wherein the sync mark reliability metric 82 represents a probability that the sync mark 24 was detected accurately. As described in greater detail below with reference to FIG. 9, the timing recovery circuit 70 may ignore a detected sync mark (not update the coarse timing recovery measurement) if the sync mark reliability metric 82 is below a threshold. The sync mark reliability metric 82 may be generated in any suitable manner, and the sync mark detector 66 implemented using any suitable circuitry.

FIG. 6 shows details of a suitable sync mark detector 66 according to an embodiment of the present invention. A data detector 84 (e.g., a slicer, peak detector, discrete time sequence detector, etc.) processes the read signal sample values 64 to detect an estimated binary data

sequence 86 that is shifted into a shift register 88. The estimated binary data sequence stored in shift register 88 is correlated with a sync mark pattern stored in register 90 using a plurality of XOR gates 92_0-92_N . In an alternative embodiment, the read signal samples 64 are correlated with expected samples of the sync mark pattern. The outputs of the XOR gates 92_0-92_N are summed 94 and the summation 96 compared 98 to a threshold 100. If the summation 98 exceeds the threshold 100 (meaning that at least N bits in the estimated data sequence 88 match the sync mark pattern 90) the sync mark detect signal 68 is activated. In this embodiment, the summation 96 is also output as the sync mark reliability metric 82, wherein the higher the summation 96 the more likely the sync mark 24 is detected accurately. The threshold 100 may be set relatively low so that a sync mark 24 is detected even in the presence of substantial signal noise (e.g., due to a media defect). The timing recovery circuit 70 evaluates the sync mark reliability metric 82 to determine whether to use the detected sync mark 24 to update the coarse timing recovery measurement.

FIG. 7A shows an alternative embodiment for generating the sync mark reliability metric 82. The read signal sample values 64 are rectified 102, and the rectified read signal sample values 104 are low pass filtered 106 to extract the DC component 108. When a sync mark is detected 68, a register 110 stores the DC component 108 of the rectified read signal, wherein the higher the DC component 108 the more likely the sync mark 24 is detected accurately.

FIG. 7B shows yet another embodiment for generating the sync mark reliability metric 82. An expected sample estimator 112 processes the read signal sample values 64 to generate a sequence of expected or ideal sample values 114. The read signal sample values 64 are subtracted 116 from the expected sample values 114 to generate a sequence of sample errors 118. A MSE generator 120 processes the sample errors 118 to compute a mean squared error (MSE) 122 which is subtracted 124 from a MAX MSE 126. When a sync mark is detected 68, a register 130 stores the output 128 of the subtractor 124, wherein the lower the MSE 122 (the higher the subtraction signal 128) the more likely the sync mark 24 is detected accurately. In one embodiment, the expected sample estimator 112 is implemented using a slicer wherein the slicer

1 levels are adjusted to compensate for the gain variations in the read signal 60 (eye pattern of FIG.
2 3B) as the head 28 crosses over a spiral track 20.

3 FIG. 8 shows still another embodiment of the present invention for generating the sync
4 mark reliability metric 82. In this embodiment, a PES generator 132 processes the read signal
5 sample values 64 representing the high frequency signal 22 in the spiral tracks 20 to generate a
6 position error signal (PES) 134 for use in maintaining the head 28 along the circular target path
7 while writing the product servo sectors. The PES generator 132 may generate the PES 134 in
8 any suitable manner, and in one embodiment, rectifies and integrates the read signal sample
9 values 64 to generate the PES 134. The magnitude of the integrated signal is also output as the
10 sync mark reliability metric 82, wherein the higher the integration the more likely the
11 corresponding sync mark 24 is detected accurately.

12 FIG. 9 shows a flow chart according to an embodiment of the present invention wherein a
13 predetermined number of consecutive sync marks 24 having a low reliability metric are ignored.
14 At step 136 a sync mark detection window is enabled as the head 28 approaches a sync mark 24
15 in a spiral track 20. At step 138, the sync mark detector 66 searches for the sync mark 24 and
16 generates the sync mark reliability metric 82. If at step 140 the sync mark 24 is missed, then at
17 step 142 a variable MISSED is incremented. If the sync mark 24 is detected at step 140, but at
18 step 144 the reliability metric is below a predetermined threshold, then at step 146 the variable
19 MISSED is incremented. If at step 148 the number of consecutive sync marks MISSED is less
20 than a predetermined number, then at step 150 the sync mark 24 is ignored (not used to update
21 the coarse timing recovery measurement). If at step 148 the number of consecutive sync marks
22 MISSED exceeds the predetermined number, then at step 152 the sync mark 24 is used to
23 generate the coarse timing recovery measurement and at step 154 the variable MISSED is reset.
24 Using the high reliability sync marks 24 to update the timing recovery measurements reduces
25 jitter in the timing recovery PLL. In addition, updating the timing recovery measurement during
26 low SNR periods (e.g., over a media defect) helps the timing recovery circuit 70 maintain

1 synchronization of the servo write clock 58 even though the sync marks 24 may be detected with
2 low reliability.

3 FIG. 10 shows an embodiment of the present invention wherein after writing the spiral
4 tracks 20₀-20_N to the disk 18 (FIG. 2A-2B), the HDA 32 is inserted into an external product
5 servo writer 156 comprising suitable circuitry for reading and processing the spiral tracks 20₀-
6 20_N in order to write the product servo sectors 56₀-56_N to the disk 18. The external product servo
7 writer 156 comprises a read/write channel 158 for interfacing with a preamp 160 in the HDA 32.
8 The preamp 160 amplifies a read signal emanating from the head 28 over line 162 to generate an
9 amplified read signal applied to the read/write channel 158 over line 164. The read/write channel
10 158 comprises circuitry for generating servo burst signals 166 applied to a servo controller 168.
11 The servo controller 168 processes the servo burst signals 166 to generate the PES. The PES is
12 processed to generate a VCM control signal applied to the VCM 30 over line 170 in order to
13 maintain the head 28 along a circular path while writing the product servo sectors 56₀-56_N. The
14 servo controller 168 also generates a spindle motor control signal applied to a spindle motor 172
15 over line 174 to maintain the disk 18 at a desired angular velocity. Control circuitry 176
16 processes information received from the read/write channel 158 over line 178 associated with the
17 spiral tracks 20₀-20_N (e.g., timing information) and provides the product servo sector data to the
18 read/write channel 158 at the appropriate time. The product servo sector data is provided to the
19 preamp 160 which modulates a current in the head 28 in order to write the product servo sectors
20 56₀-56_N to the disk 18. The control circuitry 176 also transmits control information over line 180
21 to the servo controller 168 such as the target servo track to be written. After writing the product
22 servo sectors 56₀-56_N to the disk 18, the HDA 32 is removed from the external product servo
23 writer 156 and a printed circuit board assembly (PCBA) comprising the control circuitry 34 (FIG.
24 2A) is mounted to the HDA 32.

25 In one embodiment, the external product servo writer 156 of FIG. 10 interfaces with the
26 HDA 32 over the same connections as the control circuitry 34 to minimize the modifications
27 needed to facilitate the external product servo writer 156. The external product servo writer 156

1 is less expensive than a conventional servo writer because it does not require a clean room or
2 sophisticated head positioning mechanics. In an embodiment shown in FIG. 11, a plurality of
3 external product servo writers 156_0-156_N process the HDAs 32_{i-i+N} output by an external spiral
4 servo writer 36 in order to write the product servo sectors less expensively and more efficiently
5 than a conventional servo writer. In an alternative embodiment shown in FIG. 12, an external
6 spiral servo writer 36 is used to write the spiral tracks, and the control circuitry 34 within each
7 product disk drive 16_0-16_N is used to write the product servo sectors.